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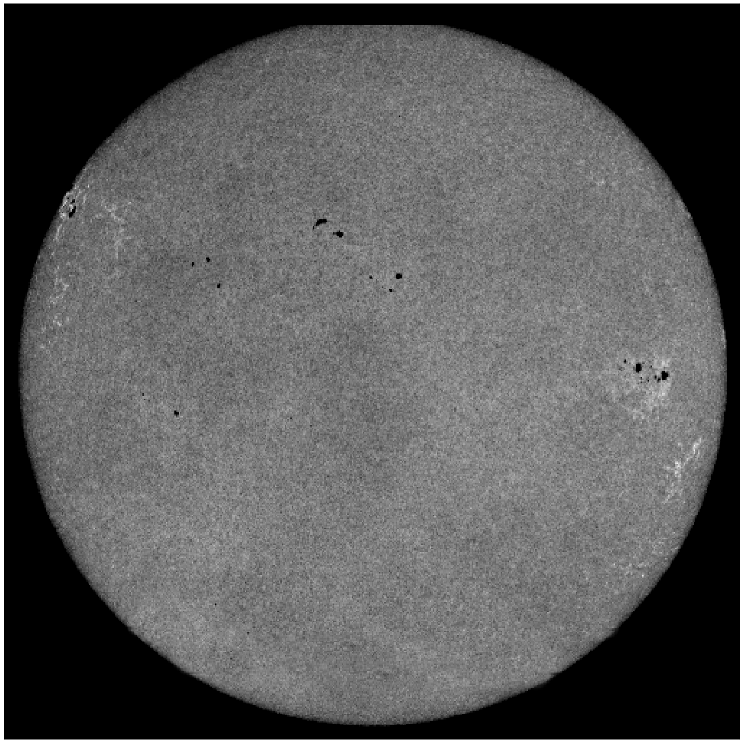
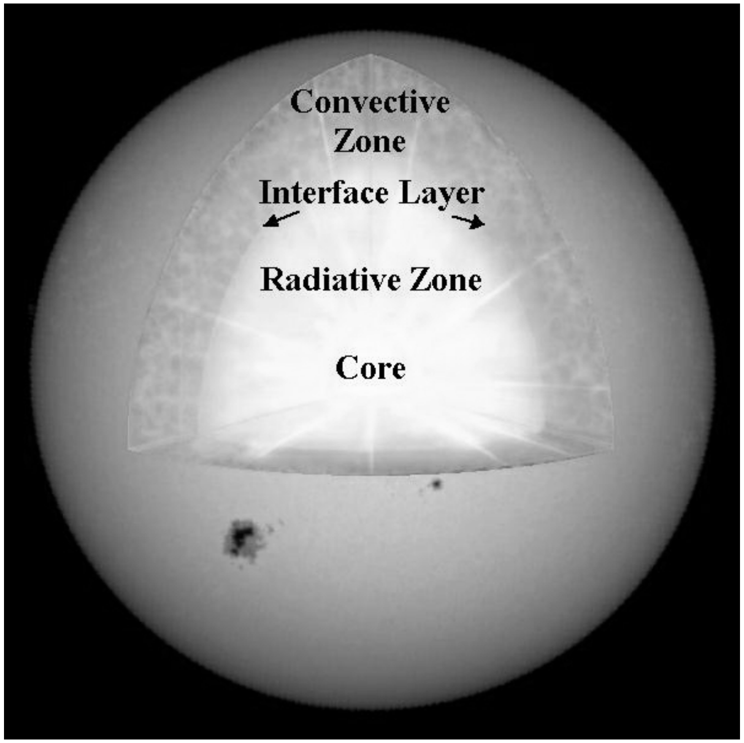
Internal structure determined by

- energy generation
- energy transfer



Interior of the sun



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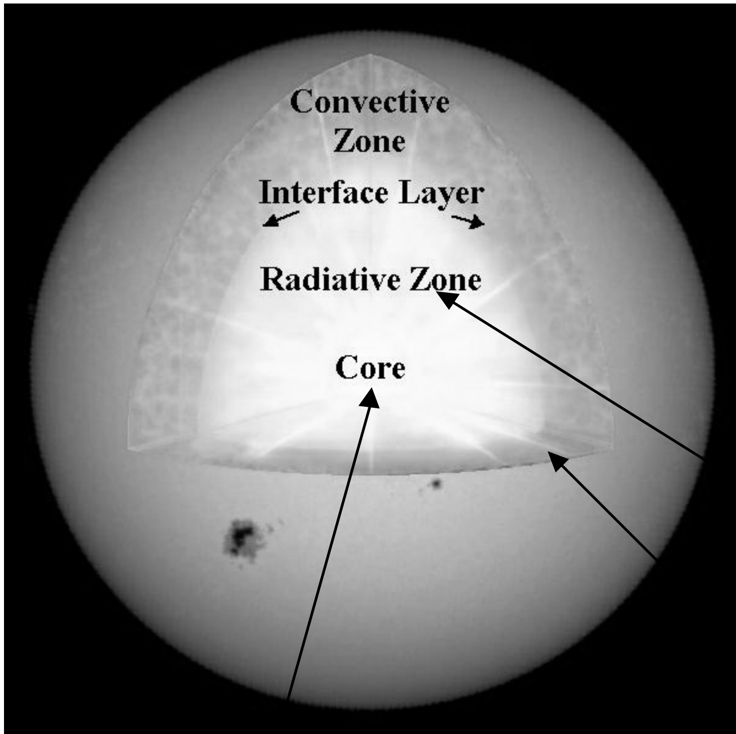

nuclear reactions require extremely high temperatures and high densities for nuclei to overcome the coulomb barrier; these conditions only exist in a small core region at the very center of the star

Main sequence stars generate energy via conversion of H into He:

4 H —> He + energy

(via proton-proton chain in low mass stars)

Energy generated in the core is transferred outward through the star; transfer is via either:

- radiation (photons)
- convection (bulk motions of the plasma)

in **low mass stars**, radiative energy transfer dominates in part of envelope above core

nearer the photosphere, the envelope becomes unstable to convective motions of the plasma, and convection takes over as the energy transfer mechanism

convective motions plus stellar rotation give rise to a **stellar dynamo** which generates the magnetic field

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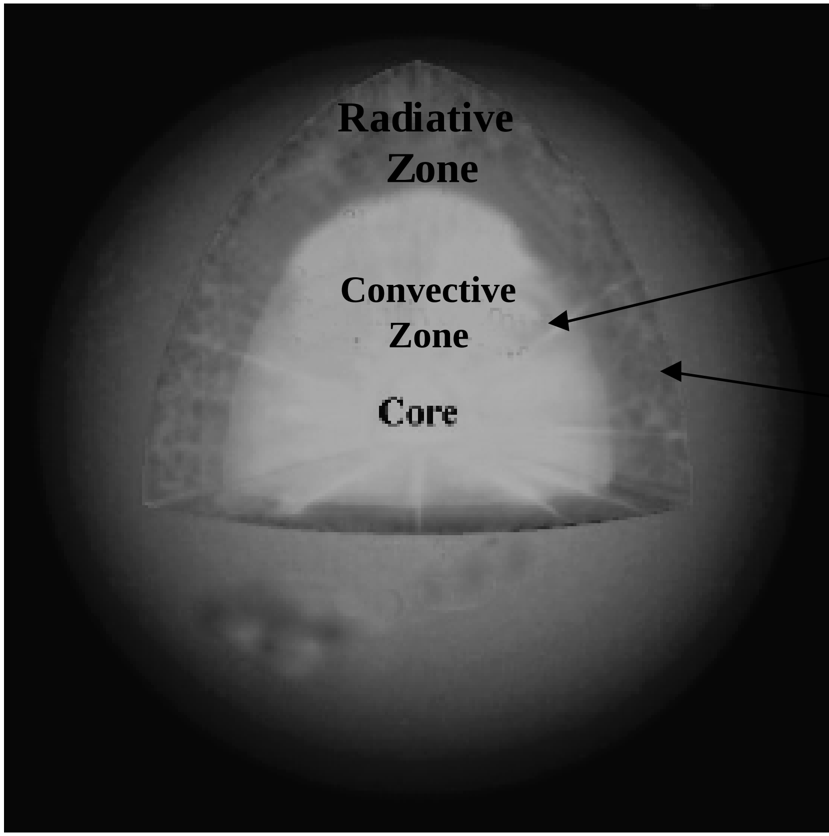

in **high mass stars**, conversion of H-He via CNO cycle (C,N, & O act as catalysts for the process)

convective energy transfer dominates in part of envelope above core

nearer the photosphere, the envelope becomes stable against convection and **radiation** takes over as the energy transfer mechanism

lack of convective motions in the outer envelope means that high mass stars should have **weak magnetic fields**

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Nuclear Evolution

- stars start out as 75% H, 25% He by mass

- as time progresses, amount of He increases, and amount of H decreases in the core

- rate at which H used up depends on the T of the core

- Core T proportional to core pressure which depends on mass since star in hydrostatic equilibrium

- more massive stars "burn" H quicker than less massive stars

- Eventually core entirely made of He => end of main sequence life for star

τ_{ms} = main sequence lifetime = 10^{10} years for a solar-mass star
τ_{ms} = 10^6 years for a 20 solar mass star

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If conversion of H => He stops

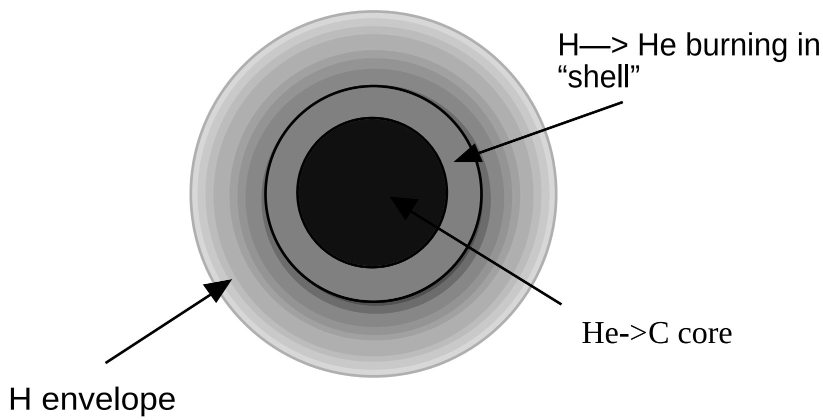
• core can no longer generate enough gas pressure to support the overlying stellar envelope

• overlying envelope squeezes down onto core, forcing core to contract

• energy production in H-burning shell increases; star becomes bigger, brighter & cooler: "**red supergiant**" phase

• overlying envelope does *PdV* work on the core; core heats up, and density increases

• if T, density increase sufficiently, star can begin to burn **He => C**



if He=>C begins ("*Helium flash*"):
• pressure in core restored
• Core pushes outward on envelope
• core expands and envelope contracts since total energy (in core and H-burning shell) produced inside star DROPS
• star becomes hotter but fainter

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Post Helium burning evolution:

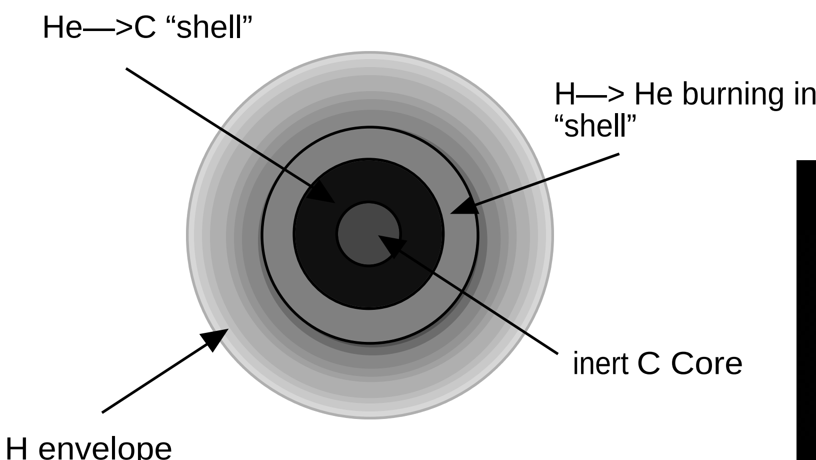
- eventually all the He in the core is converted to C
- if star massive enough, can burn C=> heavier elements (Si, O, etc)
- if star not massive enough to burn C, then this is the end of the star's evolution

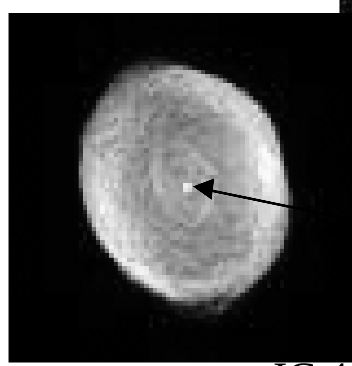
star becomes a "planetary nebula" + "white dwarf"

White Dwarf:remains of the inert C core

Planetary Nebula :remains of the stellar envelope which becomes detached from the WD

- fate of stars like the sun, up to about 3 solar masses





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The Ant Nebula

white dwarf

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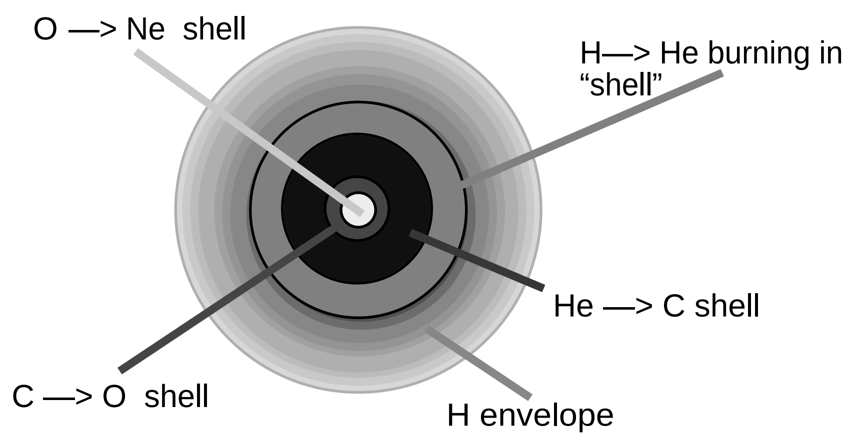
More massive stars ($M > 5\ M_{suns}$) can generate high enough core temperatures and densities to burn C (and heavier metals)

Interior of the star eventually resembles an onion with different shells of nuclear processing:



Each subsequent stage of nuclear burning takes shorter than the preceding stage:

$$\tau(\text{H burning}) \sim 0.1\ \tau(\text{He burning}) \sim 0.1\ \tau\ (\text{C burning}) \ldots$$

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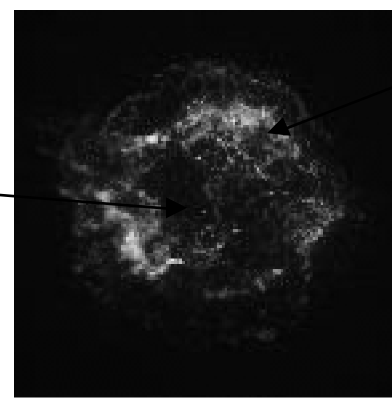
If the star's mass > 5-10 Msuns, star will fuse matter up to iron

Iron is endothermic - takes more energy to fuse or break it up than is produced by the reaction

Ultimate end of high mass star's life occurs with formation of the Fe core, since fusing (or breaking up) the Fe in the core robs the core of energy

⇒ core can no longer generate enough pressure to support envelope
⇒ no more energy generation *or* hydrostatic equilibrium
⇒ stellar envelope collapses violently onto the core
⇒ compressed core forms high density *collapsed object* (neutron star, black hole)
⇒ somehow the energy of the collapse produces an explosion which drives the stellar envelope into space => Supernova & supernova remnant

neutron star?



supernova remnant

Cas A SNR

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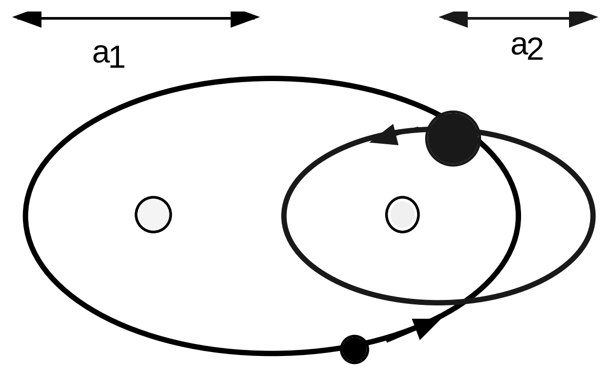
What if star has a companion?
binary stars (=gravitationally bound stellar pairs) common; orbits follow Kepler's Laws



General Orbital geometry: orbits are elliptical, share one focus

Kepler's Third Law:

$$P^2=(4\pi^2 a^3) / [G(M_1+M_2)]$$

$$a = a_1 + a_2$$

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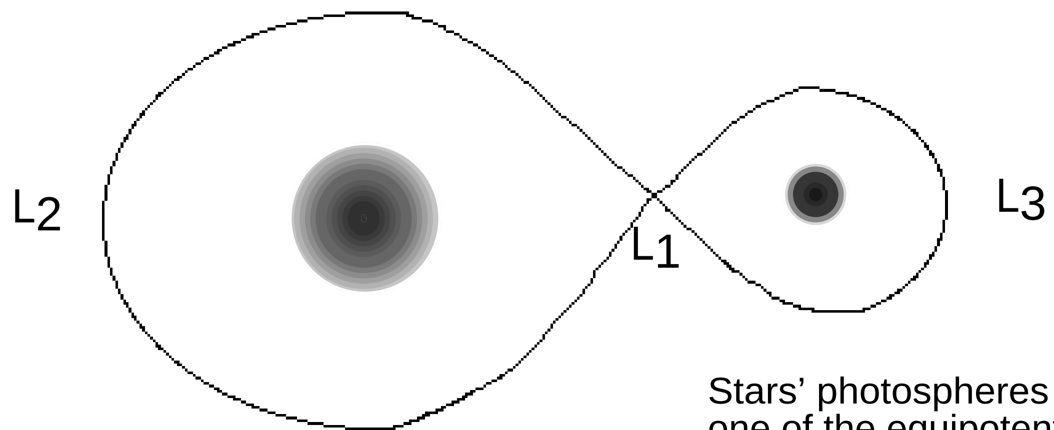
Roche Geometry: If the stars can be modelled as point sources, then the ROCHE SURFACES are defined as the effective potential due to 1) gravitational potential of each star plus 2) centrifugal potential due to orbital motion



Stars' photospheres will conform to one of the equipotential surfaces

Critical surface is defined where the equipotential surfaces cross to enclose both stars.

L's are the Langrangian points where the effective force cancels out.

Mass transfer can occur through L_1 point, L_2, point or L_3; mass can accumulate at L_4 & L_5 points.

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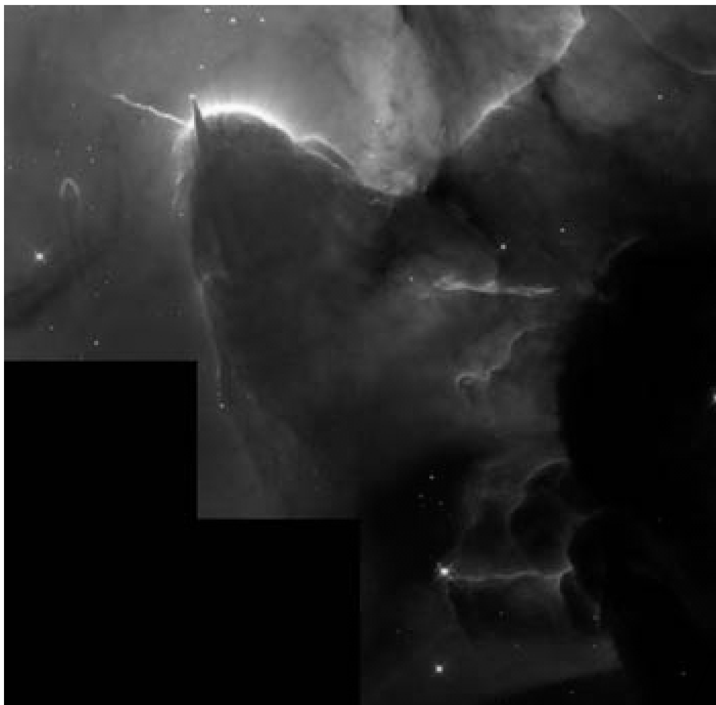
How do stars form?



The Trifid Nebula

Stars form from enormous clouds of gas (molecular gas) and dust, distributed through the disk of the Galaxy (and other galaxies)

Compression of one region of a cloud produces a small area of enhanced density => enhanced gravitational pull

surrounding gas and dust fall on the region of enhanced density, further increasing density

What causes initial compression? cloud motion through the galaxy, external agents (SNRs, stellar winds,...)

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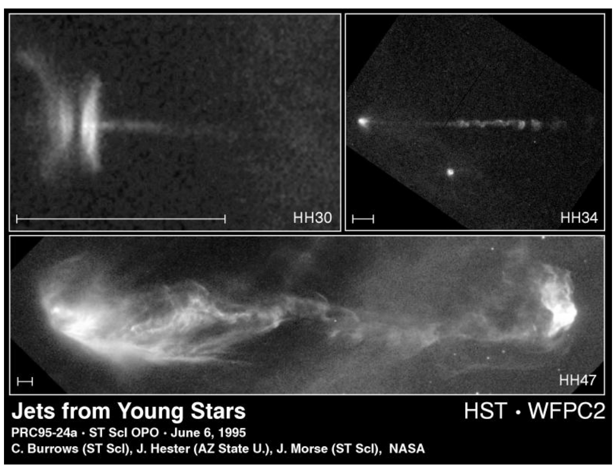
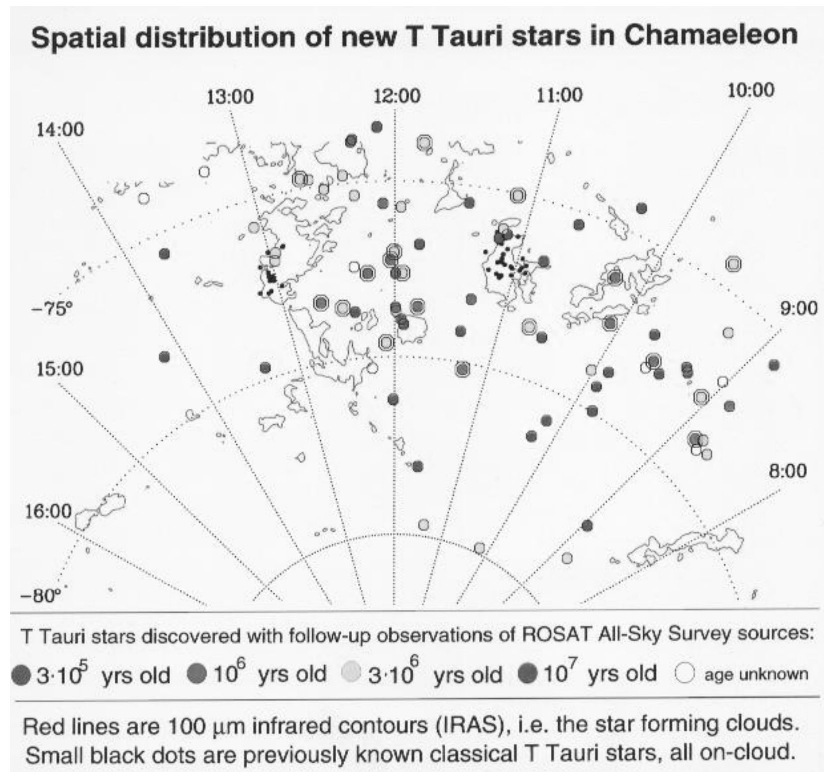
Star formation: fight between gravitational contraction and conservation of angular momentum (centrifugal acceleration)

New stars spinning quickly: strong dynamos (low-mass stars); generally strong X-ray sources

rotation causes disk formation; jets





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